

Colour psychology: the emotional effects of colour perception

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Abstract: The importance we attach to our perception of light and colour and its emotional effects is discussed with reference to experimental work. The question of whether red is a more activating colour than blue is discussed by reference to two opposing schools of thought. One is based on colour light and measured by physiological changes in the central and autonomic nervous system and the other is based on colour pigment applied in interior and exterior spaces. The question whether colour affects the subjective estimation of time and warmth is also discussed with reference to experimental work. The ongoing debate of colour aesthetics and, in particular colour preferences is discussed on a longitudinal basis for the past 40 years of teaching the subject in the Oxford School of Architecture.

Key words: longitudinal colour preference, psycho-physiological arousal, subjective time estimation and warmth, light and seasonal affective disorder, architectural context.

4.1 Introduction

The importance we attach to our perception of light and colour and its emotional effects upon us is not only celebrated by artists, poets and architects, but arouses life-long passions amongst different scientists trying to understand and measure its effects upon human beings and life itself. This chapter addresses some of these issues.

We need light to see the world around us and colour to add beauty to our aesthetic sensibility. The effects of light and colour on man, however, go beyond our common-sense assumptions and expectations; writers from poets to evolutionary biologists have praised man's good fortune. Indeed, Nicholas Humphrey, a theoretical psychologist known for his work on the evolution of human intelligence and consciousness, put forward the proposition that our ability to see colour could have evolved only because it contributes to our biological survival. Rikard Küller, the most distinguished environmental psychologist in Scandinavia, in his comprehensive annotated bibliography of over 1700 references (Küller, 1981), commissioned by the Commission Internationale de l'Eclairage (CIE), summarised the psycho-physiological literature on activation, and firmly established the importance of three systems, mediating the non-visual effects of light and colour:

1. The cutaneous system activated when ultraviolet and infrared radiation reaches the skin. Skin pigmentation and the development of vitamin D are some of the main effects.
2. The pineal–hypothalamic–pituitary system. Light affects the pineal gland where it blocks the sleep hormone melatonin, which in turn influences the hypothalamus which is involved in our emotions, and the pituitary gland which regulates other hormones.
3. The reticular activation system. Visual stimulation passing through the reticular formation activates the central nervous system as a whole. Both external stimulation through the ascending reticular activation system (ARAS) and internal activation such as thinking and personal experiences through the descending reticular activation system (DRAS) affect our state of arousal.

The impact of light on our mood and emotions is well illustrated in a recent cross-cultural study involving 1000 people in Sweden, England, Saudi Arabia and Argentina (Küller *et al.*, 2006). The results show that both England (52°N) and Sweden (56°N) exhibited serious symptoms of seasonal affective disorder, commonly known as SAD, during the winter, compared to Argentina (27°S) and Saudi Arabia (26°S). These symptoms indicated extreme tiredness, insomnia, lack of concentration, inactivity, social withdrawal and poor mood. Almost half of the population of the two northern countries exhibited some degree of seasonal disorder.

The question of whether red is a more activating colour than blue is discussed by reference to two opposing schools of thought. One is based on colour light and measured by physiological changes in the central and autonomic nervous system and the other is based on colour pigment applied in interior and exterior spaces while varying the dimensions of hue, chromatic strength and lightness. Two experiments are discussed where subjects experience realistic full-scale red and blue spaces (and rooms) and where both physiological and affective measures are taken. This is followed by looking at whether differences in hue affect our perception and feeling of warmth at the cognitive as well as the physiological level. The third area considers the hypothesis that red accelerates the subjective experience of time. These two experiments are discussed in the context of other published work over the past 80 years (1926–2009). The ongoing debate of colour aesthetics and, in particular, colour preferences is discussed on a longitudinal basis, not on the basis of a single experiment and also in relation to the context of colour applied to buildings.

Colour psychology is an area increasingly involving interdisciplinary research towards our better understanding of the influence of light and colour on our emotions (Porter and Mikellides, 2009). It is not surprising to observe that the International Association of Colour (AIC) world

conference held in Sydney 2009 attracted over 100 papers submitted on this subject. Sir Hugh Casson (1976), British interior designer, artist, influential writer and broadcaster on 20th century design and particularly noted for his role as director of architecture at the 1951 Festival of Britain on London's South Bank, wrote 'there is no truer colour responsive instrument to be found than man in all his variety, and that the best way to study colour is to use it'. If we keep on using colour and, at the same time, observe, measure and study its effects on people, we might be better for it. Antonio Gaudi, architect and designer, the most internationally prestigious figure in Spanish architecture, wrote on the 23rd January 1915 that 'Colour is life, we should not scorn this means of instilling life in our works'. If designers need any excuses for any inspiration to know more about colour while reading the learned journals and books, they might as well go out and learn how colour is used in nature; as Nicholas Humphrey put it: 'Nature has, after all been in the design business for over one hundred million years'. For over 30 years, first-year architectural students at the Oxford School of Architecture have been going out to Westonbirt Arboretum in Gloucestershire, England, during the third week of October in search of synchronic and diachronic rhyme (see Fig. 4.1).

This trip coincides with the spectacular changes of autumn colours and, based on the theoretical work of Nicholas Humphrey (1976, 2006), the students then visit the historic town of Bath in search of the same principles in the urban environment, before completing their project. This part of their project is based on Peter Smith's *The Dynamics of Delight* (2003). This introduction to colour has been a memorable and a delightful part over the years in the students educational experience on colour theory and practice.



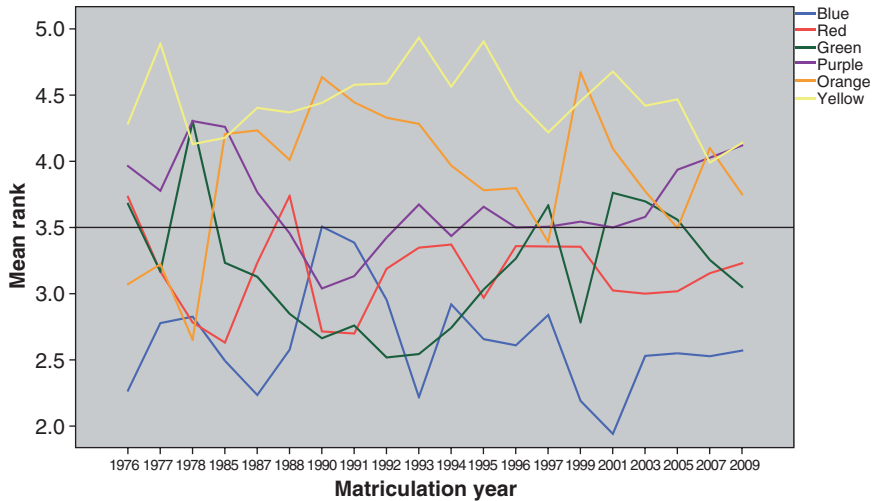
4.1 Westonbirt Arboretum, third week of October.

4.2 Colour preference: the longitudinal perspective 1970–2009

Colour preference is a topic which has attracted the ‘attention’ of nearly every researcher or writer on colour and light psychology over the past 100 years or so, from Cohn’s first empirical study in 1894 to the latest reports on the subject in colour conferences and books. Nicholas Humphrey, in the early 1970s, suggested that rhesus monkeys found blue light more pleasant than red light. In later experiments, however, he suggested that this interpretation of the behavioural results in terms ‘pleasantness’ as improbable; instead he proposed that monkeys ‘do things faster in red than blue light’. The distinguished British psychologist, Hans Eysenck, 30 years earlier obtained his PhD on the subject and proposed a ‘universal order’ of preference, possibly rooted in biology and related to our aesthetic appreciation (Eysenck, 1941). Acking and Küller (1976) in their classic ‘*Interior Colour Space*’ study ‘found differences in preference within hues far greater than between hues’ when they controlled for lightness and chromatic strength. In the AIC 1996 conference on colour psychology, five papers dealt with different aspects of colour preference. The first examined the relationship between colour chips and colour objects (Taft and Sivik, 1997); the second examined different theories of colour preference in relation to urban places (Küller, 1997); the third examined the validity of colour preference as a measure of personality (Oberascher, 1997); the fourth examined colour preferences in architectural studios (Kiran, 1996), and the fifth looked at cross-cultural differences in Japan, China and Indonesia (Sato, 1996). In AIC 2008a total of eight papers on colour preference were presented (Kortbawi *et al.*, 2008).

Why such interest? What is the practical use of these studies for the design professional? Do they raise any theoretical issues for the psychologist? What can we learn from the various measuring techniques, ranging across observational, qualitative and quantitative methods? Are these techniques valid? Some of these questions will be examined in the light of the findings of an ongoing longitudinal study of colour preferences (1970–2009) amongst architectural students at the Oxford School of Architecture. When lightness and chromatic strength are controlled within a homogenous population, in terms of age, aspirations and interests, do colour preferences change as a result of fashion, marketing and time, or are they stable over time and between the genders?

The findings of this study provide evidence for the strong popularity of and dislike for specific colours, the general order of preference proposed by Eysenck, and the influence of fashion, politics and attitudes over time. When Eysenck (1941) collected together all the published research he could find on the subject and calculated the average ranking of colour preference



4.2 Longitudinal colour preference.

in 21 060 subjects of different cultures, the general order of preference was found to be: 1, blue; 2, red; 3, green; 4, violet; 5, orange; 6, yellow. The order was highly significant and was the same for both genders. However, the actual colours have not been specified other than having been 'saturated colours'. In the Oxford longitudinal study, the colours used were matched to the same lightness and chromatic strength (2070 R90B, 2070 Y90R, 2070 B90G, 2070 R50B, 2070 Y50R, 2070 G90Y). Students took the rank-ordering preference tests during the first week of their architectural studies, before reading anything on the subject other than their interest in design. The size of the sample was 1340. The results are illustrated in Fig. 4.2.

The main results are summarised briefly below, followed by a discussion related to previous studies on the subject.

1. The order of preference for the six colours amongst architectural students remains the same as that identified by Eysenck in 1941. However, as can be seen from Fig. 4.2, while the order is the same, the strengths of the most popular and least popular colours are not so strong.
2. Blue is by far the most popular colour chosen by both genders, while yellow is the least popular colour.
3. Red and green compete in popularity for second place. For male subjects, red is their overall second preference, compared to green for females.
4. Orange is the second least popular colour by both genders.
5. Violet is middling and more popular with the females.
6. Females dislike orange and yellow more than males.

7. With regard to colour preference changes due to fashion, marketing, political attitudes and symbolism, the results of this longitudinal study provide interesting and contrasting changes in colour popularity over the four decades. For example, while orange is the overall second least popular colour over the whole period it was the most popular colour in 1970 and the second most popular colour in the 1970s, after blue.
8. Violet, on the other hand, was most popular in the 1990s, though it did not reach the popularity of orange in the 1970s.
9. Another interesting case was the increasing popularity of green since the 1970s. However, it took 20 years to displace blue as the most preferred colour, especially in the early 1990s. This can be related to the increasing popularity of green politics, the Green Party at the time and rising ecological awareness, particularly amongst the younger generation.

It is interesting to note in this context that cultural background and age have an influence on colour preference, as the same green sample (B90G 2070), while being unpopular with architectural students in the 1970s, was the most popular colour in Botswana and Kenya (Porter, 1973). Tom Porter also remarked that the same green was also the most liked colour amongst 60–90 year-olds in Oxford. It is clear therefore that while age, culture and other factors influence colour preference, there are certain stable relationships regarding the popularity of some colours over time. Support for some of the above findings comes from an unexpected area of study where colour-preference tests are used as personality tests aiming to provide a more unconscious personality profile of a person. While this analysis is beyond the scope of their paper, architecture students during the same period ranked the set of eight colours used by Dr Max Lüscher – chosen specifically for the emotional value of each colour (Lüscher, 1970). The overall order of preference based on 960 students over the years 1970–2007 was 1. blue, 2. green, 3. yellow, 4. red, 5. violet, 6. grey, 7. black and 8. brown. Though these colours were not controlled in terms of the chromatic strength and lightness dimension, blue was still the most preferred colour though it was a much darker colour (R90B 6070). Another interesting result was that the Lüscher's vibrant yellow was the third most popular colour chosen. While colour researcher Dr Leon Oberascher considers that 'a meaningful interpretation of colour preference seems to be more promising within the framework of research on everyday life-styles than personality diagnosis' (Oberascher, 1997), one must consider studies on experiments which attempted to relate abstract preferences based on aesthetic judgements to preferences related to colour in context. Every researcher is aware of the influence of age, gender, culture and fashion in generalising from colour preferences, but there are very few contextual studies that can help the

designer in practice. The early experiments by Carl-Axel Acking and Rikard Küller (1976) on interior colour and Lars Sivik (1974, 1976) on exterior colour, where colour has been systematically varied in its three dimensions of hue, chromaticness and lightness (whiteness and blackness), found lack of general results from the evaluation of the 'pleasantness factor'. They found no simple dependence either upon chromatic strength, lightness or hue. The differences found within each hue were much greater than between different hues. These studies were based on simulated colour designs of perspective interior drawings and exterior facades.

Another important issue is whether the preferred colour in abstract colour preference studies involving small colour chips is the same as when colour is part of an object. Very few studies have been published on the subject. Whitfield and Slatten (1979) consider 'prototypicality' – where certain products are identified with certain colours – as a key factor, i.e. blue potatoes or blue cheese will not be preferred as they signify something different.

Charles Taft and Lars Sivik (1997) challenged this view of the reported poor correspondence between colour chips and colour objects. Subjects rated 10 colour chips and six digital photos of objects in the same colours as the chips on semantic differential scales. The results show a good correspondence between ratings of colour chips and objects. Out of a total of 390 comparisons between ratings of chips, in only 16 cases (4 %) was the colour of the chip judged qualitatively different from the colour of the object. These were on antique chairs and computers and involved red, green and purple where the inappropriateness of colour becomes important. So prototypicality is important for certain objects which are strongly associated with certain colours. In the same way, lime green and lilac chromatic colours were not so popular in urban restoration work in Lund, Sweden (Janssens, 2001).

In another study by Sivik (1976) where deep blue and pale-lilac colours, both unusual colours in Sweden, have been used in Gothenburg, people disliked them when evaluating them in a simulation study. However, when people were asked to evaluate them in the real environment, while their evaluation of the lilac remained unchanged, their evaluation of the blue building became significantly more positive. Occupants of the building liked it even more. In another study in the old part of Stockholm involving the colour restoration of the 18th century building of Maria Ostra, colours of medium chromaticness in the yellow–red sector of the colour circle were evaluated highly in both the laboratory simulated study and in the real environment.

Küller (1980) suggests that the key factor for increased pleasantness in the built environment may lie in the balance between complexity and unity. In a restoration experiment, where two storey buildings of concrete and

wood were repainted in dark red with a black cornice, and the doors a strong green and red, when the scheme was evaluated *in situ*, there was an increase in both pleasantness evaluation as well as perceived complexity. In their latest experiments Jan Janssens and Rikard Küller (2009) looked at colour preferences of building facades in both real settings and the laboratory. The buildings included traditional houses, apartment blocks, office buildings and industrial premises. The results showed different factors influencing peoples' preferences.

- The most preferred colours were the softer yellows and white, while the least liked colours were the light and darker greens. Pink was the second least liked colour.
- Blue was the most popular colour when judged as a sample but was ranked fifth when judged as the colour of a building
- The strong yellow was fairly well liked in general both as a sample and in buildings except on the industrial building

These results show that when colours are judged on buildings the preferences do not match the preferences on samples alone. For example, while the darker blue was the most preferred colour it was not liked in buildings. They also found the relationship between the colour of the building itself and its surrounding to be highly relevant. For example, if a colour deviates a little but not too much from its surroundings it will be found attractive. Furthermore, in traditional environments the colour expectations of people are important while in modern buildings involving new technologies and new materials, unusual colorations will be more easily accepted and liked.

Colour preference studies, both experimental and contextual, will no doubt continue to interest researchers in field of colour psychology and experimental aesthetics. Theories ranging from biological and wavelength profiles to 'prototypically' or 'arousal' will be put forward to explain colour preferences and aesthetic judgments on colour and light. However, we are not yet in a position to put forward a simple theory which will account for all the empirical studies reported above.

4.3 Colour and psycho-physiological arousal

In both scientific and introspective accounts, colours have been classified and grouped in various ways depending upon the hypothesised influence or effects of such groupings (Kortbawi *et al.*, 2008). One of the most widely held groupings is that of 'warm' and 'cool' colours. Hues such as red, orange and yellow are seen, in addition to their warmth, as exciting and stimulating, whereas hues such as blue, turquoise and green are seen, in addition to their induced coolness, as calming and relaxing. Applications based on these properties of colours are not confined to the work of architects and artists

but are also used by clinicians in an attempt to pacify or calm down aggressive and anxious patients by using blue and green colours. They are also used to stimulate depressed patients by using red and orange colours (Bayes, 1970).

Some researchers have criticised these studies and suggested that the effect of hue on warmth and excitement is an intellectual one, involving cognitive processes, and not based on physiological processes which affect the whole organism. In an attempt to answer this type of criticism, namely, that the effects of these colours are not only just based on stereotyped verbal associations, but that different colours actually evoke different feeling and emotions affecting the entire organism, Robert Gerard, in his classic study (Gerard, 1958), concluded that the two wavebands of radiant energy at the opposite ends of the visible spectrum, i.e. blue and red, exert a differential biological influence on the organism as measured by general activation in the central and autonomic nervous system (EEG, blood pressure, palmar conductance level, respiration and heart rate).

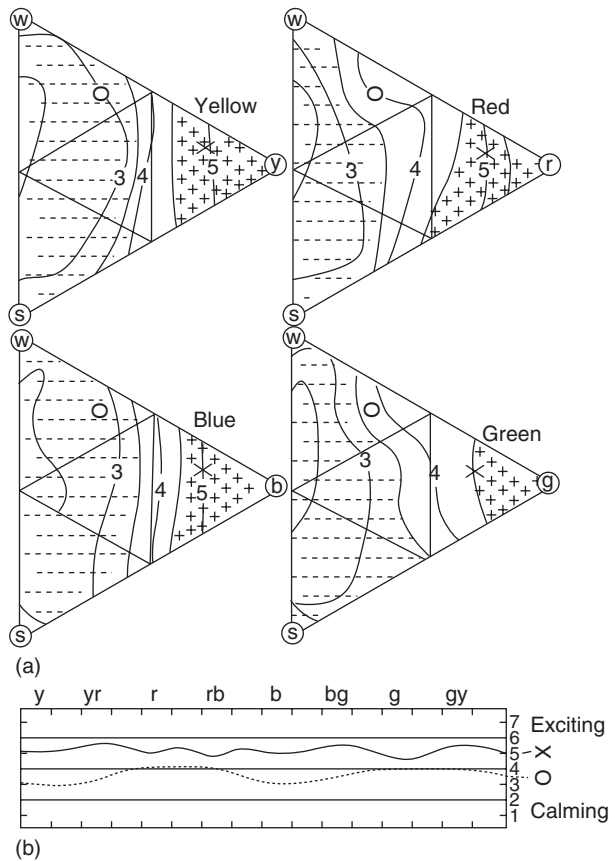
Further support is given to Gerard's work by an experiment carried out by Ali (1972). Coloured lights (blue and red) were projected directly on the eyes of 10 normal subjects for six minutes and EEGs were recorded throughout the period. The results of this study showed greater cortical arousal following the presentation of red light and lower cortical arousal following a blue light.

Parallel to these attempts to validate the reported effects of the warm and cold colours through physiological measures, there has been a different approach to establish the meanings people associate with different colours. This approach differs significantly from the above in that:

1. The three dimensions of colours (hue, chromatic strength and lightness) have been systematically manipulated in an attempt to ascertain their relationship to the dimensions of colour meaning.
2. The obtained data were treated by more powerful methods of statistical analysis, such as factor and cluster analysis, which were not available to the early researchers.

Lars Sivik (1974) was the first to demonstrate, with a technique of photo-simulation, that it was not hue which affects how exciting or calming a colour is but the chromatic strength of each hue (see Fig. 4.3). Aking and Küller (1976) showed with the use of perspective drawings of interior spaces, and later on in full-scale spaces, that weak colours give a room an impression of calmness while strong colours create an impression of excitement.

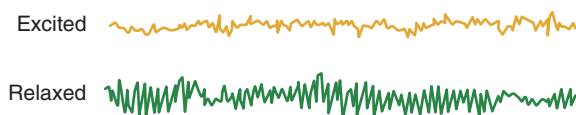
The four studies referred to above were well designed by serious researchers in the field of colour psychology. Within their own parameters, they show systematic relationships between colour and 'arousal' through physiological



4.3 Sivik study of isosemantic graphs. The reader can compare the points marked X and O in the four colour triangles to see that perceptual excitement increases as chromatic strength increases (after Sivik, 1976).

measures (Ali, Gerard) and through semantic differential analysis (Acking and Küller, Sivik). There are, however, some fundamental differences between the two sets of studies. In the first two studies the content of colour stimulation was coloured light while in the last two studies the content was colour pigment. Furthermore, in the first two studies, subjects experienced the colour light stimulation in an abstract form in the laboratory, while the last two studies were carried out in the context of real interior and exterior spaces.

The two experiments described below were intended to bridge the gap between these sets of experimental approaches. Why not measure both physiological as well as affective reactions of people? Why use patches of coloured light projected on the retina, colour slides or even small drawings



4.4 Typical EEG recording.

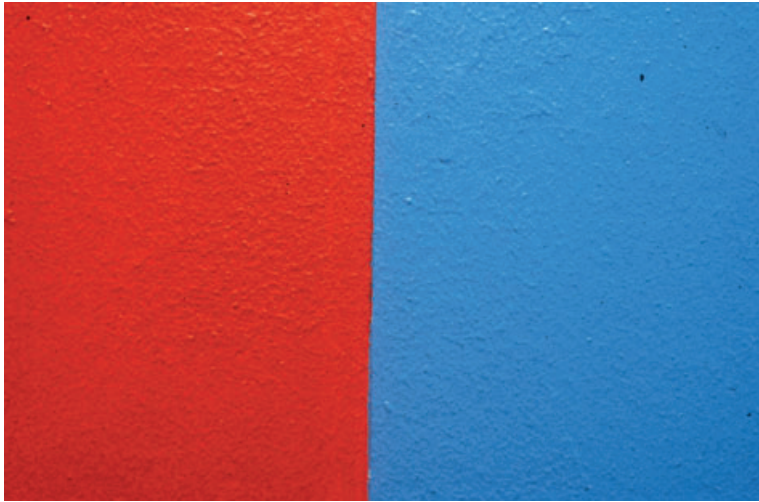
and simulated spaces when we can use surface pigments in real-life spaces – the sort of spaces we actually experience? Test exposure not only at 60 seconds intervals but over longer periods when subjects could be experiencing real environments. The main technique used in this experiment to measure activation is through EEG (see Fig. 4.4).

When a person is awake but relaxed, alpha rhythm abounds. This rather slow, high-amplitude rhythm has a tendency to disappear when the person is stimulated, but returns when the person is relaxed. Too much stimulation results in continuous blocking of alpha, involving the whole nervous system, a state generally referred to as stress. Thus, by measuring the proportion of alpha in EEG, it is possible to find out whether an environment is under-stimulating or over-stimulating. Changes in pulse rate can also be used as an indicator of activation and stress, albeit more difficult to interpret.

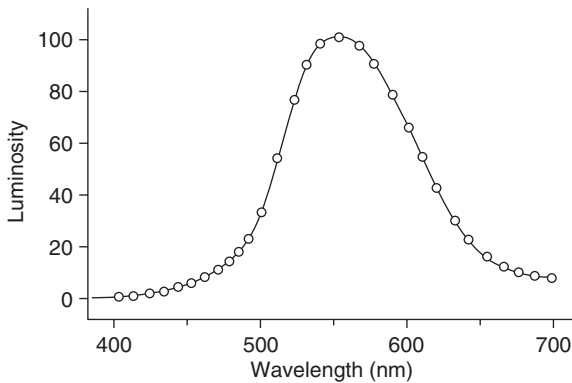
At the Environmental Psychology Unit, School of Architecture of the Lund Institute of Technology, a room measuring 3.5×4.5 m, with an adjoining control room where the monitoring equipment was placed, was used for the experiment. One half of the room was painted red (NCS 1674-Y90R), the other half was painted blue (NCS 1859 B04G). Paint covered the walls, floor, ceiling and fittings (see Fig. 4.5). Blue was chosen instead of green because the spectral sensitivity of the eye is about the same in the blue and the red regions, while the sensitivity is different in the green region (see Fig. 4.6).

The general lighting of the room was provided by Luma Colorette, a fluorescent tube which has an even spectral emission and good colour rendering (5400 Kelvin, CRI-91). It is worth noting that the colour rendering index (CRI) and colour temperature are the two most commonly used measures for the different light sources and their appearance. The CRI describes how well the light reproduces the colours of various objects faithfully in comparison with an ideal or natural source. (Rating scale is from 1–100: 0–60 poor, 60–76 good and 76–100 excellent.) Colour temperature, in Kelvin (K), describes the colour appearance of the light emitted from it. (It varies from 1500 K, for example candlelight, appearing red, 2000 K, sunrise, appearing orange, 2500 K appearing yellow, 3000–6000 K, general daylight, and 7500–10 000 appearing different shades of blue).

It was important in this study to use colour samples which would satisfy not only the Natural Colour System (NCS) parameters and colorimetric measurements, but also the correct subjective evaluation of colour



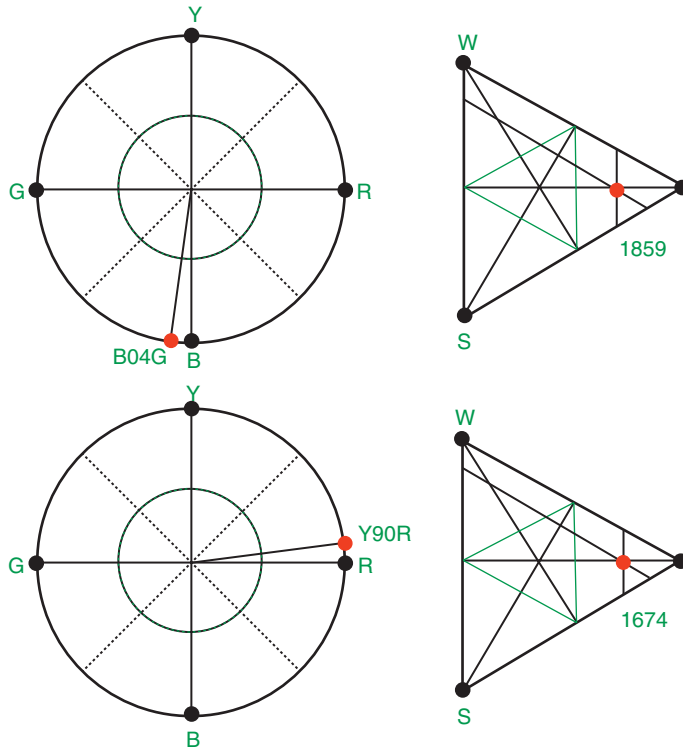
4.5 NCS red and blue room experiment colours.



4.6 The photopic sensitivity of the eye. The photopic sensitivity curve is the measure of the relative effectiveness of the different wavelengths in exciting the light sense at levels well above threshold. At these levels, the lights excite the sensation of colour mediated by the cones (after Davson 1980).

appearance. This test was satisfactory and the two colour samples conformed with the mapping of colour names in Sweden by Lars Sivik and the late Anders Hard – the inventor of the current system of NCS. NCS is a visually descriptive, scientifically based, fully documented colour notation system with supporting colour samples (see Fig. 4.7).

Temperature was maintained at a constant level through the automatic sensor at 22 °C. The participants wore lightweight garments throughout the

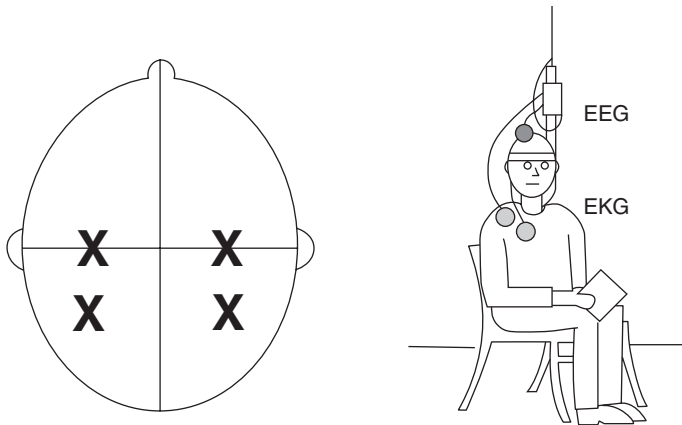


4.7 NCS colour notation for red and blue experiment colours (W, white; S, black).

experiment. In order to measure the EEG, electrodes were placed centrally and parientally, over the left and right hemispheres. A pair of electrodes was also used to record the pulse. The frequencies for the EEG analyses were in accordance with clinical classification (see Fig. 4.8).

Twenty-four subjects took part in this study. Each subject spent 20 minutes in each colour. Each condition was divided into three parts: ‘reading, fixating and closing eyes’. After the experiment, electrodes were removed and the participants’ introspection was recorded. Time estimation and galvanic skin response measures were taken during this period. It was hypothesised that the red visual field should be more activating, which should be indicated by attenuation of the alpha rhythm, and possibly the delta and theta rhythms.

The data were treated by means of several analyses of variance for both EEG and EKG recordings. The most important result of this study was, paradoxically, that there were no statistically significant differences in the experience of a red or blue space at the central nervous system. Arousal at the cortical level was the same for both red and blue. Arousal as measured



4.8 EEG body electrodes positions.

by reduced alpha was, in fact, in the opposite direction from the predicted one: there was more alpha and theta in the red visual field than in the blue one. There was also more delta activity (a brain activity indicative of relaxed and sleepy condition) in the red visual field than in the blue one.

At the autonomic nervous system level, there were no differences in EKG (pulse rate, arrhythmia) and galvanic skin response. Although autonomic measures are not accurate indicators of arousal and are often more susceptible to individual variation, they produced almost identical mean scores for the two conditions. There were differences in all EEG frequencies between the male and female groups, but these were not the differences we were looking for. There were no differences between either the male subjects or the female subjects with regard to the red and blue spaces.

The results of this experiment support the findings of Sivik (1974) and Acking and Küller (1976): provided we control chromatic strength and lightness, there are no differences between the two hues as far as excitement is concerned. In another study involving two seminar spaces, one painted red (BSI 04E53) and the other turquoise (BSI 16E53), both high in chromatic strength, two groups of subjects (architecture students and laymen) evaluated the two spaces as equally stimulating (Mikellides, 1979).

In this experiment, the strongest red paint on the market was tested. Its actual specified strength was 15 % more than the blue sample under standardised conditions. The two colours used were judged to be subjectively equal in chromatic strength and lightness. Yet no differences were found. The implications of this research for design are clear. For colour exposure of up to 20 minutes, they support Sivik's affective–connotative studies that chromatic strength (saturation) is the key dimension affecting how exciting



4.9 Experimental blue room.

or calming a colour is perceived to be and not the dimension of hue as was previously thought by colour design manuals.

In the second experiment, two identical spaces, measuring 2.8×2.9 m, were painted red and blue respectively in the lighting laboratory at Lund University (NCS 1958Y90R and NCS 2158B09G) (Figs 4.9 and 4.10). Appointments were individually made with 24 male and female subjects for two three-hour sessions per subject on two different occasions within a two-week period. During the two periods, EEG and EKG recordings were taken and the subjects completed various forms measuring a variety of subjective reactions, including temperature and time estimation as well as environmental description by means of semantic differential scales and story writing.

Special attention was given to the design of the interior spaces. The aim was to make each room feel as normal as possible without losing the distinct feeling of immersion in blueness or redness. Two special abstract oil paintings were commissioned from the Swedish artist Gunnar Sandin, to add some character to each room. The floor was covered with matt grey linoleum. The curtains were drawn so that the subject was not tempted to watch the outside world, yet offering an unmistakable feeling of a homely window. The curtains were white with a faint floral pattern of either red or blue of low chromatic strength (NCS, $C = 20\%$). The entrance to each experimental room was covered with a full drape instead of a door to add a little more interest to the space. Temperature was maintained at around 22°C by means of thermostats.

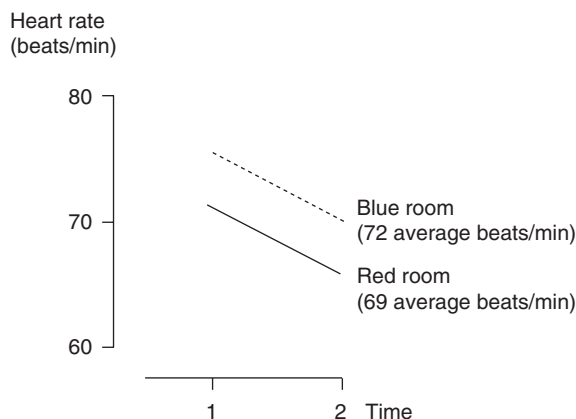
The most important result of this study is that as far as cortical arousal is concerned there is positive support to the hypothesis that red is a more activating colour than blue as indicated by difference in delta frequency ($P = 0.018$) and the strong tendency in alpha ($P = 0.161$). Delta rhythm is



4.10 Experimental red room.

indicative of a drowsy state and characterised by high-amplitude, low-frequency waves; the difference between the two colours in delta was observed in both hemispheres and in both stages when measurements were made, i.e., during the first and second hour of colour exposure. During the second period of exposure, subjects were more relaxed (as indicated by an increase in delta activity) for both colours. As far as alpha activity is concerned, there was a strong trend in support of the main hypothesis. This tendency, however, did not reach statistical significance. This suggests that after the subjects have been in a room for nearly two hours the effect of colour is even stronger than during the first hour. There were no differences in the theta and beta frequencies between the colours. All the anovas reported here were also carried out with room illumination as a covariate; this did not alter the results presented here. As far as cortical activity is concerned, the results of this experiment support, in a qualified way, the previous results of Ali (1972) and Gerard (1958) with coloured light.

In the autonomic nervous system, however, the picture is very different. In this experiment, pulse rate was higher in the blue room at 71.5 beats per



4.11 Mean heart rate in blue room and red room after 1 = 40 min (fix 1) and 2 = 110 min (fix 2).

minute and lower in the red room at 68.4 beats per minute ($P = 0.03$) (Fig. 4.11). These results are in the opposite direction to the hypothesis stated by Gerard (1958). They are also in the opposite direction to the hypothesis formulated by all other researchers (Wilson, 1966; Jacobs and Hustmyer, 1974). Paradoxically, all researchers who stated that there will be higher heart rate in the red condition (whether light or pigment) did not provide any support for their hypothesis (Gerard, Jacobs and Hustmyer). The only other colour study which offered an alternative hypothesis to heart rate was that of Küller (1976). In observing that the heart rate was slower in a colourful room than in a grey one at one-hour, two-hour and three-hour intervals, he put forward the hypothesis that cortical arousal is accompanied by cardiac deceleration. This line of theorising is also in accordance with work by Lacey (1956), and Lacey *et al.* (1963).

Another interesting finding is in the case of arrhythmia which was higher in response to red than blue. Is this negative relationship between heart rate and variability of heart rhythms another case where a compensatory homeostatic mechanism is working within the autonomic nervous system? The combined use of variability and level of heart rhythms is certainly a novel way of evaluating the autonomic balance, which merits further investigation.

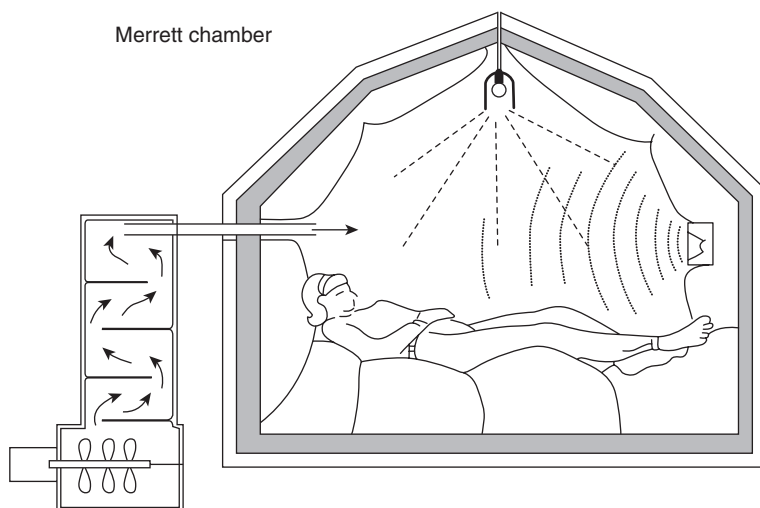
There are several theoretical implications and practical applications of this research. At the theoretical level, the validity and reliability of the various cortical and autonomic measures is brought into question. The link between EEG and EKG, as well as their relationship to affective measures, is also of theoretical interest. The hypothesis regarding cortical arousal and cardiac deceleration also deserves more experimental work. At the practical level, chromatic strength was shown to be important at the

cognitive–affective level through a variety of subjective studies. First impressions could be important to the designer and there appear to be no differences in the most saturated red and blue colours available commercially in affecting visual excitement (Mikellides, 1990). However, longer periods of up to two hours show differences in hue affecting our organism at the physiological level, provided the colours used are not too overpowering and when colour constancy is controlled by leaving enough reference points unpainted.

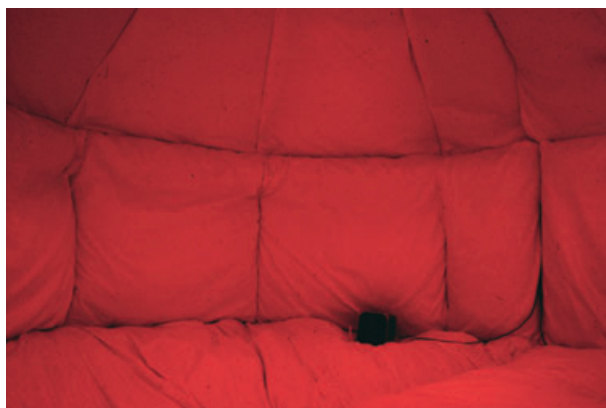
4.4 Colour and subjective time estimation

The review of the literature on colour and time estimation (Küller and Mikellides, 1993) does not resolve the conflicting reports regarding the hypothesis that red accelerates the subjective passage of time. The experimental evidence from all published studies to date using both coloured light and colour pigment at various exposure times has shown no consistent differences in the estimation of time intervals. Neither is the hypothesis that greater physiological arousal causes the acceleration of subjective time supported by Caldwell and Jones (1985) using 30- and 45-second intervals (coloured light) or Mikellides (1990) using 25- and 95-minute intervals (surface pigment). The various direct implications of this work reported in books and design manuals are not therefore borne out by our knowledge of the subject based on perceptual and laboratory studies. Whereas there are consistent differences between perceptual and laboratory studies in the subjective feeling of warmth (see Section 4.5), for time estimation there are conflicting reports within the perceptual studies, as well as within laboratory studies. The likelihood is that other variables, such as individual differences, arousal, preferences and context, mediate in these findings. The interaction between and interdependence among these variables may create a formidable task for future research. This is illustrated in the experiment by Humphrey and Keeble (1977) who found that background noise decreased the time monkeys spent in red compared to white lights, but this applied only to those monkeys who find the noise aversive in the first place! In another study using a specially designed acoustic chamber – The Merrett Chamber – at the Oxford School of Architecture (Figs 4.12 and 4.13), subjects spent periods of five or eight minutes in red and blue coloured light conditions. Although subjective time was over-estimated, no significant differences were found between the two colours.

All that may be tentatively said at this stage is that if exposure to red accelerates the subjective passage of time for short intervals (Smets, 1969; Humphrey and Keeble, 1977), then the observation cited in Porter and Mikellides (1976) that factory workers spent less time in toilets painted red than blue may be explained by the faster subjective time clock hypotheses



4.12 Merrett chamber.



4.13 Inside the Merrett chamber.

and may be said to have some repercussions for spaces involving short stay intervals! However, the studies involving longer time intervals at Lund and Oxford do not lend themselves to this hypothesis. Therefore, the case for the direct effects of colour on time estimation is not made.

4.5 Colour and the subjective feeling of warmth

Just as in the review of the psychological literature on colour and emotional arousal, there are conflicting directives between colour connotation studies and laboratory experiments with regard to the importance of the hue

dimension on the subjective feeling of warmth and heat. Furthermore, there is the observation by artists and scientists that although blue is considered cold and cool, the blue part of a gas flame is hotter than the orange or red part! Indeed, when James Turrell, the renowned artist and psychologist, gave the keynote address to the Oslo International Colour Conference 'Colour Between Art and Science', in October 1998, he made the impassionate plea to 'stop teaching the colour wheel unless you are going to teach the spectrum'. He went on to say, 'Stop teaching colour symbology. Red is not warm and cool is not blue, it is just the opposite'.

The problem is that all the anecdotal reports that red is considered a warm colour and blue a cold colour are strongly supported by the vast majority of the published perceptual and cognitive studies (Morgan and English, 1926; Sivik, 1974; Hogg *et al.*, 1979; Hutchings, 2004). These studies used colour samples, simulated colour spaces in the form of colour slides and drawings, and coloured light in a variety of contexts on a longitudinal basis. This shows that time, taste, culture or other intervening variables could not have been responsible for the consistency of their findings. However, none of the five laboratory studies to date (Berry, 1961; Bennett and Ray, 1972; Fanger *et al.*, 1977; Green and Bell, 1980; Mikellides, 1990), which attempted to measure the difference by means of behavioural, physiological and temperature estimation techniques, succeeded in finding a measurable difference of any practical importance.

What are the implications of these studies for the designer? There is no doubt that the inducement of visual warmth by exposure to red light or red paint is elicited in a variety of contexts. Men and women from various cultures and various ages report this apparent warmth consistently and, as such, it has direct design implications for the professional. Architects are involved not only in designing buildings but in creating spaces with certain perceived qualities and atmosphere. By manipulating the hue dimension, they can create a space which people will perceive as warm or cold at the cognitive level. Whether designers want to provide an immediate impression of warmth or coldness as people pass through a space or spend some time in it, the impression of apparent warmth is real in the sense of being consistently reported as such.

The hue-heat hypothesis has in fact been given support by Fanger *et al.* (1977), although the difference in perceived temperature associated with colour was small at 0.4°C, and was argued by the three experimenters to be of no practical significance. This study, however, supports the notion that the direction of apparent warmth along the line of the perceptual studies may have some basis at the physiological level, which could be detected by the development of more refined techniques in the future. However, the implication of the hue-heat hypothesis for the practising engineer, as compared to the architect who is interested in direct measurable difference in

comfort rating, is not there. As such, it cannot be used for energy conservation in any serious way, and the scepticism of heating engineers is understandable. In fact, regarding the only study where participants spent long periods of time (Mikellides, 1990), there were statistically significant differences between the first and second hour temperature evaluations; that is, the perceived temperature was estimated colder in the second period (after 90 minutes) by a magnitude of 0.8°C in a red room and 0.7°C in a blue room, – while real temperature went up by 0.5°C . At the same time, no statistically significant differences between the two rooms were found as far as colour was concerned. This experiment epitomises the existing state of knowledge as far as the conflicting conclusions between the perceptual and laboratory studies are concerned; for while the same subjects reported no differences between the two rooms in temperature estimation, highly significant differences ($P < 0.001$) were obtained in the subjective evaluation of apparent warmth based on the semantic scale of warmth (1), cold (7) – mean score for red = 1.8 and mean score for blue = 4.7. This observation was also supported by the participants' comments in the open-ended question regarding the atmosphere of the room, as well as their story writing. Clearly the validity of the hue–heat hypothesis depends upon whether the design implications concerned are considered at the cognitive level or at the physiological level.

James Turrell's passionate plea to stop teaching the colour wheel and colour symbology adds another dimension to the debate. Perhaps the lack of support of the laboratory experiments to date is a testimony to his plea above supporting the blue-flame hypothesis. Perhaps also Richard Gregory's conclusion (1997) is appropriate here in that 'there is a conflict between designing experiments simple enough for analysis and sufficiently complex to reveal the full richness of phenomena. So science is an art. Like art it is not completely mastered.'

4.6 Conclusions and further reading

Readers can see the various practical as well as theoretical conclusions at the end of each section covered in this review. With regard to further reading, the references which follow will provide a comprehensive coverage of the literature on the subject. Readers are asked to use their own judgement in evaluating the validity of the specific experiments and in deciding whether they consider the physiological experiments to be of more value more than the cognitive/affective approaches. Furthermore, they should consider whether the colour stimulation is from coloured light or pigment, and whether this research is published in reputable journals. At least designers will be aware of the limitations of our knowledge, where conflicting results are found, and base their creative designs on what we do know. The

author also hopes that future research will include both physiological as well as affective measures, not one as opposed to the other. Wherever possible, the diachronic and longitudinal dimension should be encouraged. New technologies and materials have now made it possible to introduce innovative ways of bringing colour into our homes, offices and urban spaces. The current fascination with colour change and colour animation is constantly changing our responses and attitudes to colour and light to a much greater degree than ever before. It is important to rethink the traditional role of the architect/designer in this ever-changing world by focusing on both the context and content of colour stimulation.

4.7 Sources of further information and advice

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